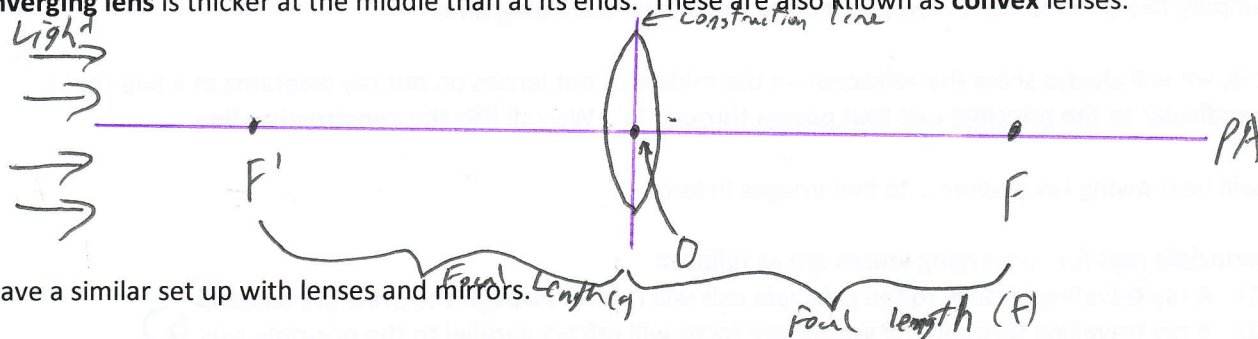


Unit V: Optics

Converging Lenses

A lens is a transparent optical device with a curved surface. Therefore, it can be thought of as a transparent device made up of a very large number of flat surfaces put together at slightly different angles.

A **converging lens** is thicker at the middle than at its ends. These are also known as **convex** lenses.

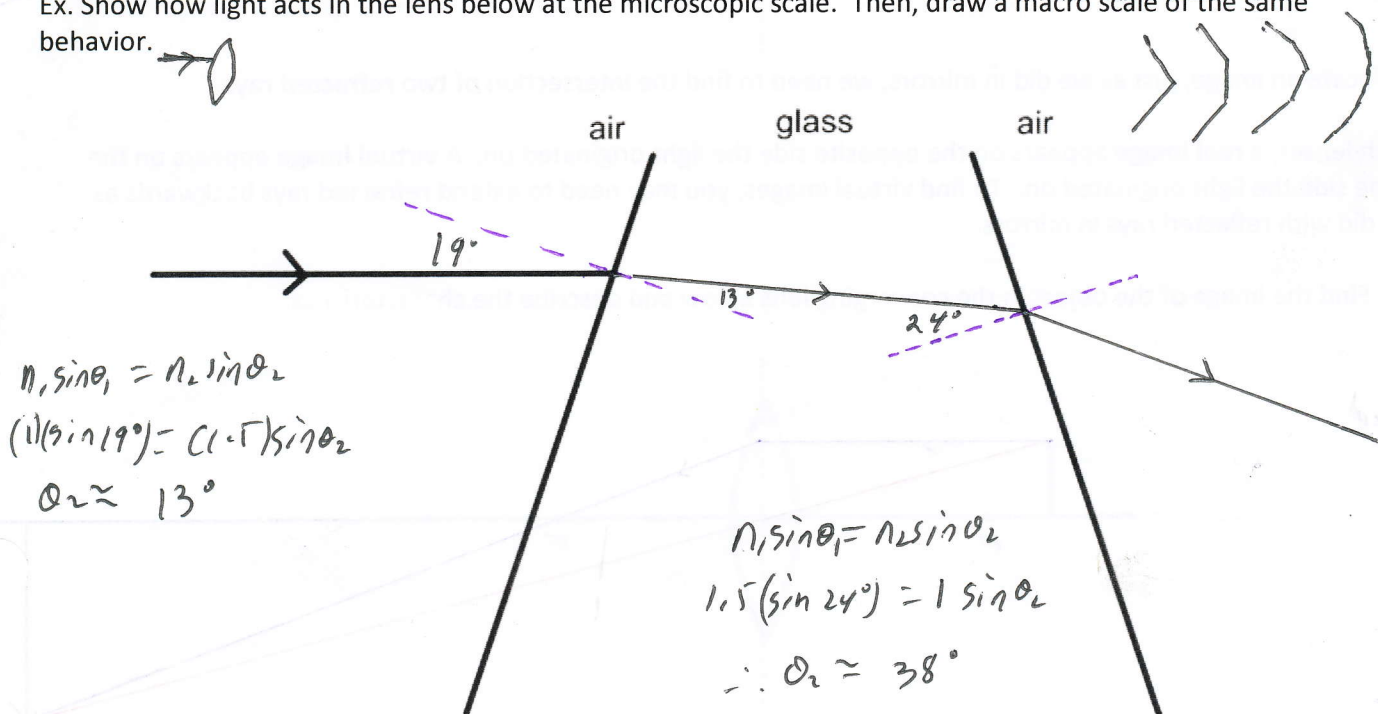


We have a similar set up with lenses and mirrors. Focal length (f)

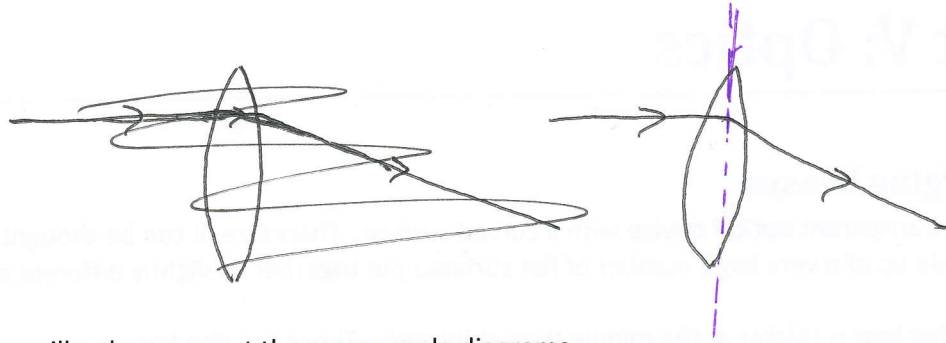
- The **optical center** of the lens is denoted as 'o'.
- The **principle axis** is an imaginary line perpendicular to the surface of the lens that travels through the optical center.
- The **principle focus (F)** is the point that rays parallel to the principle axis appear to converge through for a converging lens. For a converging lens, this will always be on the opposite side the light is originating on.
- The **secondary focus (F')** is a focal point on the opposite side of the principle focus. For a converging lens, this will always be on the same side that the light is originating on.
- Both the focal points are the same distance away from 'o'. This distance is known as the **focal length (f)**.

When light hits a lens, it will get refracted twice, once at each boundary. Again, we can think of each lens with many flat sides.

Ex. Show how light acts in the lens below at the microscopic scale. Then, draw a macro scale of the same behavior.



Macro Scale:



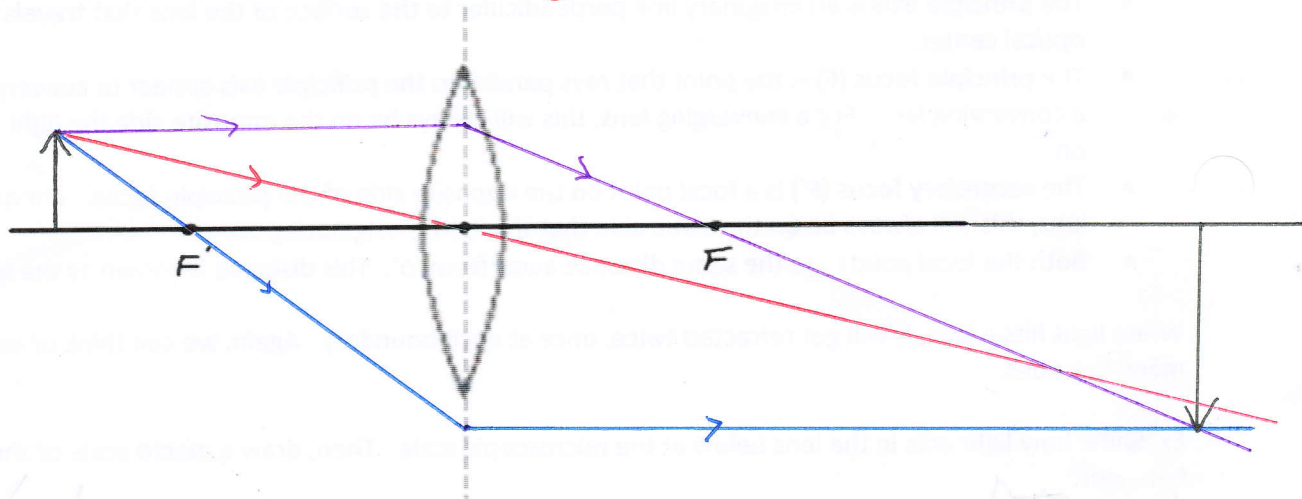
To simplify this process we will only represent the macro-scale diagrams.

That is, we will always show the refraction in the middle of our lenses on our ray diagrams at a line that is perpendicular to the principle axis that passes through 'o'. We call this the **construction line**.

We will be drawing ray diagrams to find images in lenses.

The principle rays for converging lenses are as follows:

- 1) A ray traveling parallel to the principle axis will refract through the principle focus. (1)
- 2) A ray travelling through the **secondary focus** will refract parallel to the principle axis. (2)
- 3) A ray travelling through 'o' will continue on its path. (3)

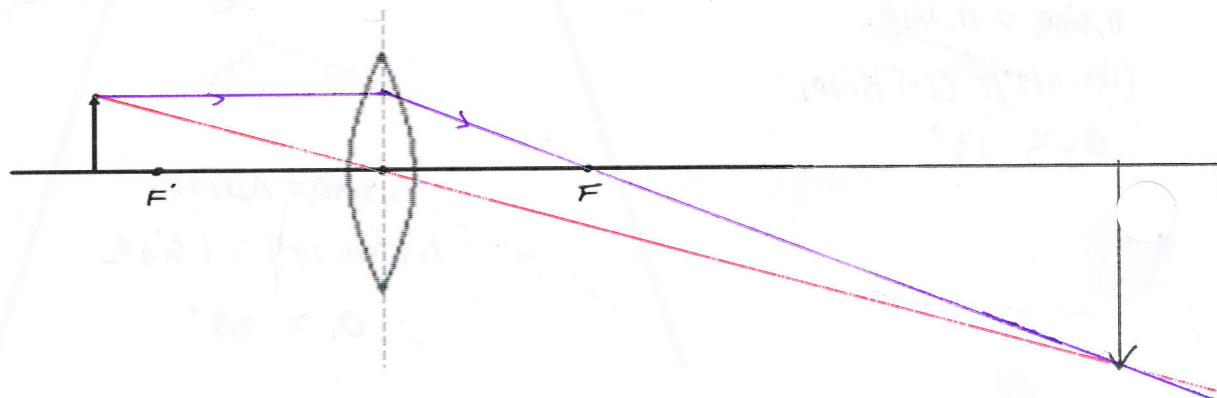


To locate an image, just as we did in mirrors, we need to find the intersection of two **refracted rays**.

With lenses, a **real image** appears on the opposite side the light originated on. A **virtual image** appears on the same side the light originated on. To find virtual images, you may need to extend refracted rays backwards as we did with reflected rays in mirrors.

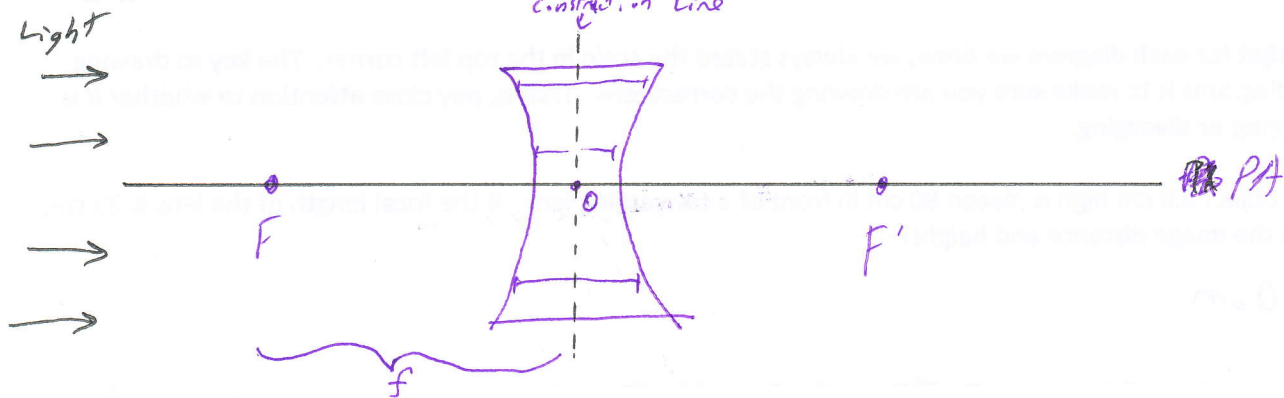
Ex. Find the image of the object in the converging lens below and describe the characteristics:

Inverted
Real
Bigger
Past F



Diverging Lenses

A **diverging lens** is a lens that is thinner in the middle than it is on its ends.

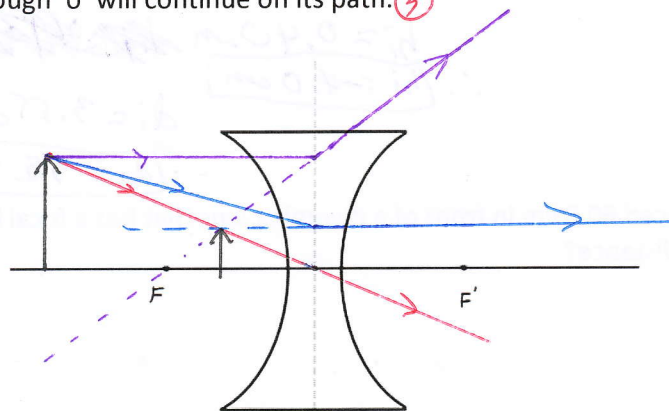


A diverging lens has the same basic set up as a converging lens. However, the principle focus is on the same side that light is originating on.

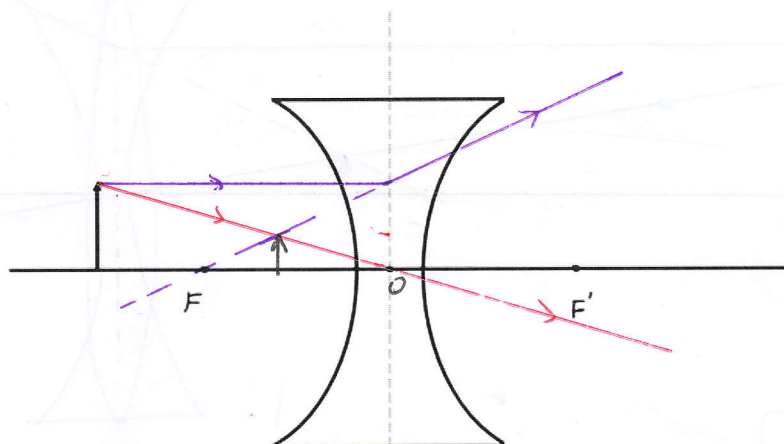
Instead of the principle focus being a point at which light converges to, it is the place where light appears to diverge from. Therefore, since light is not actually passing through this point, we think of the point as **virtual**.

The principle rays for a diverging lens are as follows:

- 1) A ray that travels parallel to the principle axis appears to refract from the **principle focus**. ①
- 2) A ray that travels towards the **secondary focus** will refract parallel to the principle axis. ②
- 3) A ray that travels through 'o' will continue on its path. ③



Ex. Locate the image of the object below:



Smaller
Virtual
Between F and O
Upright

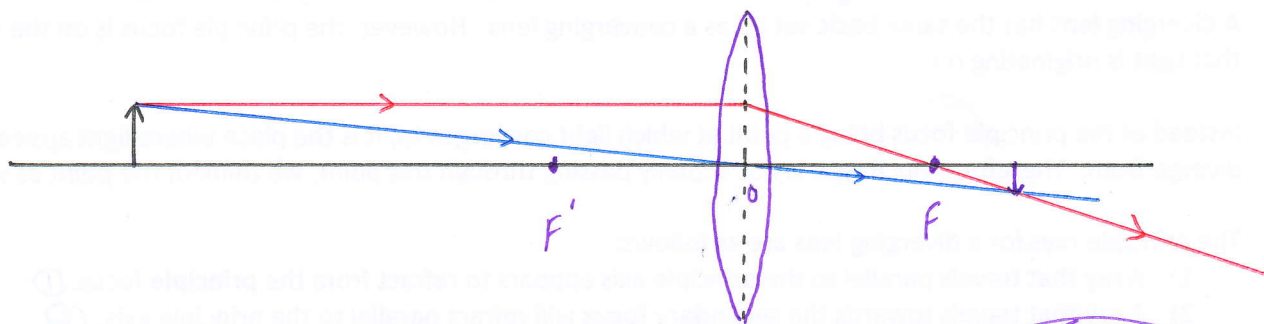
Scale Diagrams with Lenses

Drawing scale diagrams with lenses is very similar to that we did with mirrors.

Recall that for each diagram we drew, we always stated the scale in the top left corner. The key to drawing these diagrams is to make sure you are drawing the correct lens. That is, pay close attention to whether it is **converging** or **diverging**.

Ex. An object 8.0 cm high is placed 80 cm in front of a converging lens. If the focal length of the lens is 25 cm, what is the image distance and height?

$$1\text{ cm} = 10\text{ cm}$$



$$h_i = 0.40\text{ cm}$$

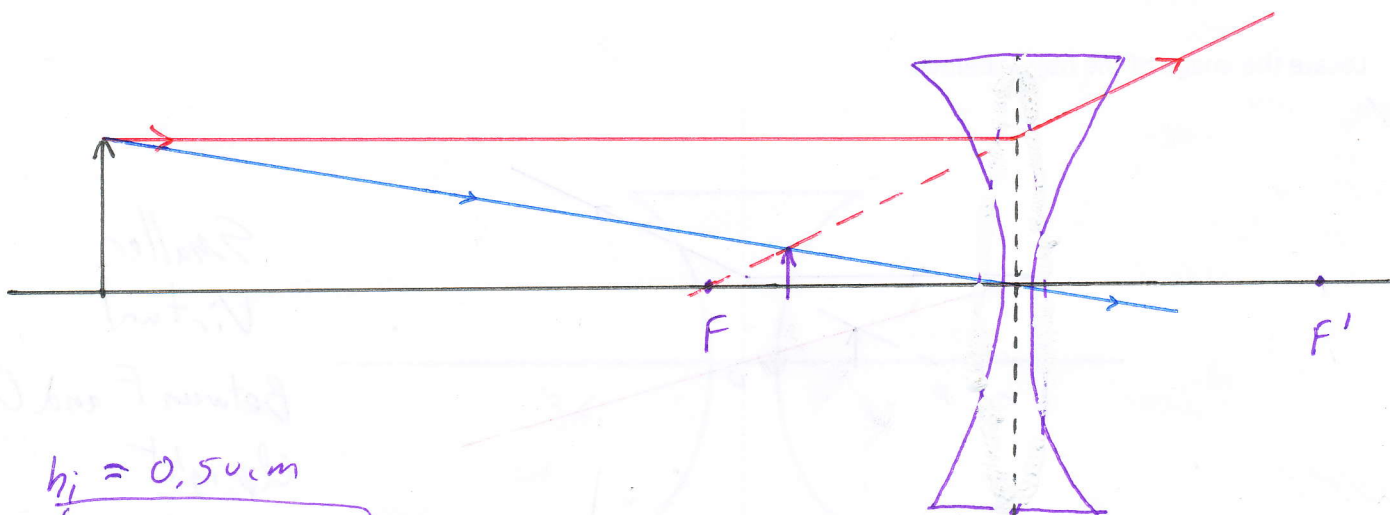
$$\therefore \boxed{h_i = -4.0\text{ cm}}$$

$$d_i = 3.55\text{ cm}$$

$$\therefore \boxed{d_i = -35.5\text{ cm}}$$

Ex. A light 10.0 cm high is placed 60.0 cm in front of a diverging lens that has a focal length of 20.0 cm. What is the image height and image distance?

$$1\text{ cm} = 5\text{ cm}$$



$$h_i = 0.50\text{ cm}$$

$$\therefore \boxed{h_i = 2.5\text{ cm}}$$

$$d_i = 3.00\text{ cm}$$

$$\therefore \boxed{d_i = -15.0\text{ cm}}$$

Math with Lenses

Although drawing ray diagrams give us the solution to lens problems, they can be inaccurate because of measuring errors. Therefore, to get a more precise solution, we can use the following formulas:

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$M = \frac{h_i}{h_o}$$

$$M = -\frac{d_i}{d_o}$$

$$\frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

Where:

f = focal length

d_i = image distance

d_o = object distance

h_i = image height

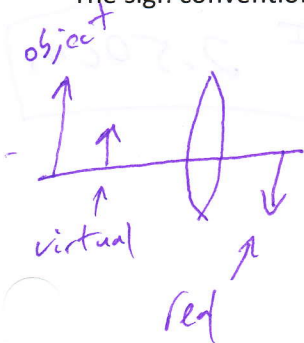
h_o = object height

M = magnification

The sign conventions for lenses are as follows:

| | Positive | Negative |
|-------|------------------|----------------|
| d_o | Always | Never |
| d_i | Real | Virtual |
| h_o | Always | Never |
| h_i | Virtual, Upright | Real, Inverted |
| f | Converging | Diverging |
| M | Virtual, Upright | Real, Inverted |

← Always with a diverging lens!



Ex. An object 8.0 cm high is placed 80 cm in front of a converging lens. If the focal length of the lens is 25 cm:

a) What is the image distance?

$$\begin{aligned} d_i = ? \\ h_o = 8.0 \text{ cm} \\ d_o = 80 \text{ cm} \\ f = 25 \text{ cm} \end{aligned} \quad \left| \quad \begin{aligned} \frac{1}{f} &= \frac{1}{d_i} + \frac{1}{d_o} \\ \frac{1}{f} - \frac{1}{d_o} &= \frac{1}{d_i} \\ \frac{1}{25 \text{ cm}} - \frac{1}{80 \text{ cm}} &= \frac{1}{d_i} \end{aligned} \right| \quad \left(\frac{1}{40 \text{ cm}} \right)^{-1} = \left(\frac{1}{d_i} \right)^{-1} \quad \left| \quad d_i \approx 36 \text{ cm} \right.$$

b) What is the height of the image?

$$\begin{aligned} h_i = ? \\ \frac{h_i}{h_o} &= -\frac{d_i}{d_o} \\ h_i &= -\frac{d_i h_o}{d_o} \end{aligned} \quad \begin{aligned} h_i &= -\frac{(36 \text{ cm})(8.0 \text{ cm})}{80 \text{ cm}} \\ h_i &\approx -3.6 \text{ cm} \end{aligned}$$

Ex. A light 10.0 cm high is placed 60.0 cm in front of a diverging lens that has a focal length of 20.0 cm. What is the image height and image distance?

$$\begin{array}{l}
 h_i = ? \\
 d_i = ? \\
 h_o = 10.0 \text{ cm} \\
 d_o = 60.0 \text{ cm} \\
 f = -20.0 \text{ cm}
 \end{array}
 \left| \begin{array}{l}
 \frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \\
 \frac{1}{f} - \frac{1}{d_o} = \frac{1}{d_i} \\
 \frac{1}{(-20.0 \text{ cm})} - \frac{1}{60.0 \text{ cm}} = \frac{1}{d_i} \\
 \left(\frac{-1}{20} \right) = \left(\frac{1}{d_i} \right)
 \end{array} \right|
 \begin{array}{l}
 \frac{-15}{1} = d_i \\
 \boxed{-15.0 = d_i}
 \end{array}
 \left| \begin{array}{l}
 \frac{h_i}{h_o} = -\frac{d_i}{d_o} \\
 h_i = -\frac{d_i h_o}{d_o} \\
 h_i = -\frac{(-15.0 \text{ cm})(10.0 \text{ cm})}{60.0 \text{ cm}} \\
 \boxed{h_i = 2.50 \text{ cm}}
 \end{array}
 \right.$$

Just Eyeball It

How does your eye "see"?

- 1.) Light reflects off an object to your eye.
- 2.) Light refracts through the cornea.
- 3.) Light travels through the pupil.
- 4.) Light is refracted through the lens and forms an inverted real image on the retina.
- 5.) The retina sends messages to the brain via the optic nerve.
- 6.) The optical center of your brain creates the image that you "see".

Vision Defects

Myopia

- nearsightedness
- corrected using diverging, concave lens
- the distance between the lens and retina is too large causing the image to focus in front of the retina.

Hypermetropia

- farsightedness
- corrected using converging, convex lens
- the distance between the lens and the retina is too small causing the image to form "behind" the retina.

Astigmatism

- This happens when the lens of the eye has more than one focal point because the lens is rippled instead of smooth
- astigmatic people cannot see in fine detail
- corrected using cylindrical lenses